PHILOSOPHICAL TRANSACTIONS.

I. THE BAKERIAN LECTURE.—*Experimental Researches in Electricity.—Twenty-second Series.*

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§ 28. *On the crystalline polarity of bismuth and other bodies, and on its relation to the magnetic form of force.*

¶ i. *Crystalline polarity of bismuth.* ¶ ii. *Crystalline polarity of antimony.* ¶ iii. *Crystalline polarity of arsenic.*

2454. MANY results obtained by subjecting bismuth to the action of the magnet have at various times embarrassed me, and I have either been contented with an imperfect explanation, or have left them for a future examination: that examination I have now taken up, and it has led to the discovery of the following results. I cannot, however, better enter upon the subject than by a brief description of the anomalies which occurred, and which may be obtained at pleasure.

2455. If a small open glass tube have a bulb formed in its middle part and some clean good bismuth be placed in the bulb and melted by a spirit-lamp, it is easy afterward, by turning the metal into the tubular part of the arrangement, to cast it into long cylinders: these are very clean, and when broken are seen to be crystallized, usually giving cleavage planes, which run across the metal. I prepare them from 0·05 to 0·1 of an inch in diameter, and, if the glass be thin, usually break both it and the bismuth together, and then keep the little cylinders in their vitreous cases.

2456. Taking some of these cylinders at random and suspending them horizontally between the poles of the electro-magnet (2247.), they presented the following phe-

nomena. The first pointed axially; the second, equatorially; the third, equatorial in one position, and obliquely equatorial if turned round on its axis 50° or 60°; the fourth, equatorially and axially under the same treatment; and all of them, if suspended perpendicularly, pointed well, vibrating about a final fixed position which seemed to have no reference to the form of the cylinders. In all these cases the bismuth was strongly diamagnetic (2295, &c.), being repelled by a single magnetic pole, or passing off on either side from the axial line between two poles. A similar piece of finely-grained or granular bismuth was, under the same circumstances and at the same time, affected in a perfectly regular manner, taking up the equatorial position (2253.), as a body simply diamagnetic ought to do. The cause of these variations was finally traced to the regularly crystalline condition of the metallic cylinders.

¶ i. *Crystalline polarity of bismuth.*

2457. Some bismuth was crystallized in the usual manner by melting it in a clean iron ladle, allowing it partly to congeal, and then pouring away the internal fluid portion. Pieces so obtained were then broken up by copper hammers and tools, and groups of the crystals separated, each group or piece consisting only of those crystals which were symmetrically arranged, and therefore likely to act in one direction. If any part of the fragments had been in contact with the iron ladle, it was cleared away by rubbing on sandstone and sand-paper. Pieces weighing from 18 grains to 100 grains were thus easily obtained.

2458. The electro-magnet employed in the first instance was that already described (2247.), having moveable terminations which supplied either conical, round, or flat-faced poles. That the suspension of the bismuth might be readily effected and unobjectionable as to magnetic influence, the following arrangement was generally adopted. A single fibre of cocoon silk, from 12 to 24 inches in length, was attached to a fit support above, and made fast below to the end of a piece of fine, straight, well-cleaned copper wire, about 2 inches in length; the lower end of this wire was twisted up into a little head, and then furnished with a pellat of cement, made by melting together a portion of pure white wax, with about one-fourth its weight of Canada balsam. The cement was soft enough to adhere by pressure to any dry substance, and sufficiently hard to sustain weights up to 300 grains, or even more. When prepared, the suspender was subjected by itself to the action of the magnet, to ascertain that it was free from any tendency to point, or be affected; without which precaution no confidence could be reposed in the results of the experiments.

2459. A piece of selected bismuth (2457.), weighing 25 grains, was hung up between the poles of the magnet, and moved with great freedom. The constituent cubes were associated in the usual manner, being attached to each other chiefly in the line joining two opposite solid angles; and this line was in the greatest length of the piece. The instant that the magnetic force was on, the bismuth vibrated strongly

about a given line, in which, at last, it settled; and if moved out of that position it returned, when at liberty, into it; pointing with considerable force, and having its greatest length *axial.*

2460. Another piece was then selected, having a flatter form, which when subjected to the magnetic power, pointed with the same facility and force, but its greatest length was equatorial: still the line according to which the cubes tended to associate diametrally, was, as before, in the *axial* direction. Other pieces were then taken of different forms, or shaped into various forms by rubbing them down on stone, but they all pointed well; and took up a final position, which had no reference to the shape, but was manifestly dependent on the crystalline condition of the substance.

2461. In all these cases the bismuth was diamagnetic, and strongly repelled by either magnetic pole, or from the axial line. It was affected only whilst the magnetic force was present. It set in a given constant position perfectly determinate; and, if moved, always returned to it, unless the extent of motion was above 90°, and then the piece moved further round and took up a new position diametrically opposed to the former, which it then retained with equal force, and in the same manner. This phenomenon is general in all the results I have to refer to, and I will express it by the word diametral:—diametral set or position.

2462. The effect occurs with a single magnetic pole, and it is then striking to observe a long piece of a substance, so diamagnetic as bismuth, repelled, and yet at the same moment set round with force, axially or end on, as a piece of magnetic substance would do.

2463. Whether the magnetic poles employed (2458.) are pointed, round, or flat-faced, still the effect on the bismuth is the same: nevertheless, the form of the poles has an important influence of a subordinate kind; and some forms are much more fitted for these investigations than others. When pointed poles are employed, the lines of magnetic force (2149.) rapidly diverge, and the force itself diminishes in intensity to the middle distance from each pole. But when flat-faced poles are used, though the lines of power are curved and vary in intensity at and towards the edges of the flat faces, yet there is a space at the middle of the magnetic field where they may be considered as parallel to the magnetic axes, and of equal force throughout. If the flat faces of the poles be square or circular, and their distance apart about one-third of their diameter, this space of uniform power is of considerable extent. In my experience the central or axial portion of the magnetic field is sensibly weaker than the circumjacent parts; but, then, there is a small screw-hole in the middle of each pole face, for the attachment of other forms of termination.

2464. Now the law of action of bismuth, as a *diamagnetic* body, is, that it tends to go from stronger to weaker places of magnetic force (2267. 2418.); but as a *magnecrystallic* body it is subject to no effect of the kind; and is as powerfully affected by lines of equal force as by any other. So a piece of amorphous bismuth, suspended in a magnetic field of uniform power, seems to have lost its diamagnetic force alto-

gether, and tends to acquire no motion but what is due to torsion of the suspending fibre, or currents of air: but a piece of regularly crystallized bismuth is, in the same situation, very powerfully affected by virtue of its magnecrystallic condition.

2465. Hence the great value of a magnetic field of uniform force; and, if, hereafter, in the extension of these investigations to bodies having only a small degree of crystalline power, a perfectly uniform field should be required, it could easily be given by making the form of the pole face somewhat convex, and rounded at the edges more or less. The required shape could be ascertained by calculation, or perhaps better in practice, by the use of a little test cylinder of bismuth in the granular or amorphous state, or of phosphorus.

2466. In addition to these observations it may be remarked, that small crystals, or masses of crystals, and such as approach in their general shape to that of a cube or a sphere, are better than large or elongated pieces; inasmuch, as if there be irregularities in the force of a magnetic field, such pieces are less likely to be affected by them.

2467. When the crystal of bismuth is in a magnetic field of equal strength, it is equally affected whether it be in the middle of the field or close up to one or the other magnetic pole; *i.e.* the number of vibrations in equal times appears to be equal. Much care, however, is required in estimating it by such means, because, from the occurrence of two positions of unstable equilibrium in the equatorial direction, the vibrations in large arcs are much slower than those in small arcs; and it is difficult in different cases to adjust them to the same extent of vibration.

2468. Whether the bismuth be in a field of intense magnetic force or one of feeble powers; whether the magnetic poles are close up to the piece, or are opened out until they are five or six inches or even a foot asunder; whether the bismuth be in the line of maximum force, or raised above, or lowered beneath it; whether the electric current be strong or weak, and the magnetic force, therefore, more or less in that respect; if the bismuth be affected at all it is always affected in the same manner.

2469. The results are, altogether, very different from those produced by diamagnetic action (2418). They are equally distinct from those dependent on ordinary magnetic action. They are also distinct from those discovered and described by PLÜCKER, in his beautiful researches into the relation of the optic axis to magnetic action; for there the force is equatorial, whereas here it is axial. So they appear to present to us a new force, or a new form of force in the molecules of matter, which, for convenience sake, I will conventionally designate by a new word, as the *magnecrystallic* force.

2470. The direction of this force is, in relation to the magnetic field, *axial* and *not equatorial*; this is proved by several considerations. Thus, when a piece of regularly crystallized bismuth was suspended in the magnetic field, it pointed; keeping it in this position, the point of suspension was removed 90° in the equatorial plane (2252.), so that when again freely suspended, the line through the crystal,

which was before horizontal in the equatorial plane, was now vertical; the piece again pointed, and generally with more force than before. The line passing through the crystal, coincident with the magnetic axis, may now be taken as the line of force; and if the process of a quarter revolution in the equatorial plane be repeated, however often, the crystal still continues to point with the assumed line of force in the magnetic axis, and with a maximum degree of power. But now, if the point of suspension be removed 90° in the plane of the axis, *i. e.* to the end of the assumed line of force, so, that when the crystal is again freely suspended this line is vertical; then, the crystal presents its peculiar effect at a *minimum*, being almost or entirely devoid of pointing power, and exhibits in relation to the magnet, only the ordinary diamagnetic force (2418.).

2471. Now if the power had been equatorial and polar, its maximum effect would not have been produced by a change of the point of suspension through 90° in the equatorial plane, but by the same change in the axial plane, and any similar change after that in the axial plane, would not have disturbed the maximum force; whereas a single change of 90° in the equatorial plane, would have brought the line of force vertical (as in PLÜCKER's case of Iceland spar), and reduced the results to a minimum or zero.

2472. The directing force, therefore, and the set of the crystal are in the *axial* direction. This force is, doubtless, resident in the particles of the crystal. It is such, that, the crystal can set with equal readiness and permanence in two diametral positions: and that between these there are two positions of equatorial equilibrium, which are, of course, unstable in their nature. Either end of the mass or of its molecules, is to all intents and purposes, both in these phenomena, and in the ordinary results of crystallization, like the other end; and in many cases, therefore, the words *axial* and *axiality* would seem more expressive than the words *polar* and *polarity*. In presenting the ideas to my own mind, I have found the meaning belonging to the former words the most useful.

2473. On placing the *metal* in other positions, and therefore in a constrained condition, no alteration of the state or power of the bismuth, either in force or direction, is produced by the power of the magnet, however strong its enforcement or long its continuance.

2474. It is difficult readily to describe the position of this force in relation to the crystal, though most easy to ascertain it experimentally. The form of the bismuth crystals is said to be that of a cube, and of its primitive particle a regular octohedron. To me the crystals do not seem to be cubes, but either rhomboids or rhombic prisms, approaching very nearly to cubes. My measurements were very imperfect and the crystals not regular; but as an average of several observations, the planes were inclined to each other at angles of $91\frac{1}{2}$° and $88\frac{1}{2}$°; and the boundary lines of a plane at $87\frac{1}{2}$° and $92\frac{1}{2}$°. Whatever be the true form, it is manifest upon inspection, that the aggregating force tends to produce crystals having more or less of the rhomboidal

shape and rhombic planes; and that these crystals run together in symmetric groups, generally in the direction of their longest diameters. Now the line of *magnecrystallic* force almost always coincides with this direction where the latter is apparent.

2475. The *cleavage* of bismuth crystals removes the solid angles and replaces them by planes; so that there are four directions producing the octohedron. These cleavages are not (in my experience) made with equal facility, nor do they produce planes equally bright and perfect. Two, and more frequently one, of these planes is more perfect than the others; and this, the most perfect plane, is that which is produced at the most acute solid angle (2474.); and is generally easily recognized. When a bismuth crystal presents many planes of cleavage and is suspended in the magnetic field, one of these planes faces towards one of the magnetic poles, and its corresponding plane, if it be there, towards the other; so that the line of magnecrystallic force is perpendicular to this plane: and this plane corresponds to the one which I have already described as being, generally, the most perfect, and replacing the acute angle of the crystal.

2476. A single crystal of bismuth was selected and cut out from the mass by copper tools, and the places where it had adhered were rubbed down on sand-paper, so as to give the fragment a cube-like form with six planes; four of these planes were natural. One of the solid angles, expected to be that terminating or in the direction of the line of magnecrystallic force, was removed, so as to expose a small cleavage plane, which was bright and perfect, as also was expected. When suspended in the magnetic field with this plane vertical, the crystal instantly pointed with considerable force, and with the plane towards either one or the other magnetic pole; so that the magnecrystallic axis appeared now to be horizontal and acting with its greatest power. When this axial line was made vertical, and the plane therefore horizontal, the position being carefully adjusted, the crystal did not point at all. Being now suspended in succession at all the angles and faces of the cube, it always pointed with more or less force; but always so that a line drawn perpendicularly through the indicating cleavage plane (representing therefore the line of force) was in the same vertical plane as that including the magnetic axis: and, finally, when the bright cleavage plane was horizontal and the line of directive force therefore vertical, inclining it a little in a given direction, would make any given part of the crystal point to the magnetic poles.

2477. A *group* of bismuth crystals, the apex of which was terminated by a single small cleavage facet, was found to give the same results.

2478. Occasionally groups of crystals (2457.) occurred which did not seem capable of being placed in some one position in which they lost all directive power, but seemed to retain a minimum degree of force. It is very unlikely, however, that all the groups should be perfectly symmetric in the arrangement of their parts. It is more surprising that they should be so distinct in their action as they are. In reference to bismuth, and many other bodies, it is probable that magnetic force will

give a more important indication in relation to the essential and real crystalline structure of the mass than its form can do.

2479. I have already stated that the *magnecrystallic* force does not manifest itself by attraction or repulsion, or, at least, does not cause approach or recession, but gives *position* only. The *law* of action appears to be, that, *the line or axis* of MAGNECRYSTALLIC *force* (being the resultant of the action of all the molecules), *tends to place itself parallel, or as a tangent, to the magnetic curve or line of magnetic force, passing through the place where the crystal is situated.*

2480. I now broke up masses of bismuth which had been melted and solidified in the ordinary way, and, selecting those fragments which appeared to be most regularly crystallized, submitted them to experiment. It was almost impossible to take a small piece which did not obey the magnet and point more or less readily. By selecting the thin plates with perfect cleavage planes, I readily obtained specimens which corresponded in all respects with the crystals; but thicker plates or angular pieces often proved complicated in the results, though apparently simple and regular as to form. Occasionally, the cleavage plane, which I have beforehand taken for that perpendicular to the line of force (2475.), has proved not to be the plane supposed; but, after observing experimentally the direction of the magnecrystallic power, I have always either found, or else obtained by cleavage, a plane corresponding to it, possessing the appearance and character before described (2475.). Bismuth plates from the one-twentieth to the one-tenth of an inch in thickness, and bounded by parallel and similar planes, when broken up often proved, upon ocular examination, to be compounded and irregular.

2481. When a well-selected plate of bismuth (mine are about 0·3 of an inch in length and breadth, and 0·05, more or less, in thickness) is hung up by the edge in the magnetic field, it vibrates and points, presenting its faces to the magnetic poles, and setting diametrally (2461.). By whatever part of the edge it is suspended, the same results follow. But if it be suspended horizontally, the cleavage planes of the fragment and of the magnetic axis being parallel to the plane of motion of the plate, then it is perfectly indifferent; for then the line of magnecrystallic force is perpendicular to the line of magnetic force in every position that it can take.

2482. But if the plate be inclined only a very small quantity from this position, it points, and that with more force as the planes become more nearly vertical (2475.); and the phenomena before described with a crystal (2476.), can here be obtained with a fragment from a mass, and any part of the edge of the plate made to point axially, by elevating or depressing it above or below the horizontal plane.

2483. If a number of these crystalline plates be selected at the magnet, they may afterwards be built up together, with a little good cement (2458.), into a mass which has perfectly regular magnecrystallic action; and in that respect resembles the

crystals before spoken of (2459. 2468. 2476.). In this manner, also, the *diamagnetic* effect of the bismuth may be neutralized; for it is easy to build up a prism whose breadth and thickness is equal, and this being hung with the length vertical, points well and without any interference of diamagnetic action.

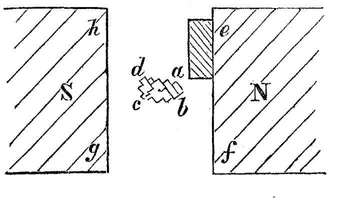
2484. By placing three equal plates at right angles to each other, a system is obtained, which has lost all power of pointing under the influence of the magnet, the force being, in every direction, neutralized. This represents the case of finely crystallized or amorphous bismuth. The same result (having the same nature) may be obtained by taking a selected uniform mass of crystals (2457.), melting it in a glass tube and resolidifying it: unless the crystallization is large and distinct, which rarely happens, the piece obtained is apparently without magnecrystallic force. A like result is also obtained by breaking up the crystal and putting the small fragments or powder into a tube, and submitting the whole to the force of the magnet.

2485. These experiments on bismuth are not difficult of repetition; for, except those which require the sudden production or cessation of the magnetic force, the whole may be repeated with an ordinary horse-shoe magnet. A magnet, with which I have wrought considerably, consists of seven bars placed side by side, and being fixed in a box with the poles upwards, presents two magnet cheeks, an inch and a quarter apart, between which is the magnetic field, having the lines of force in a horizontal direction. The poles of the magnet should be covered, each with paper, to prevent communication of particles of iron or rust. The best place for the piece of bismuth is, of course, between the poles; not level however with their tops, but from 0·4 to 1·0 inch lower down (2463.), that the effect of flat-faced poles may be obtained. If it be desired to strengthen the lines of magnetic force, this may be done by introducing a piece of iron between the poles of the magnet, and so, by virtually causing them to approach, lessen the width of the magnetic field between them.

2486. The magnet I used would sustain 30 lbs. at the keeper; but employing small pieces of bismuth, I have easily obtained the effects with magnets weighing themselves not more than 7 ounces, and able to sustain only 22 ounces; so that the experiments are within the reach of every one.

2487. Whilst the crystal of bismuth is in the magnetic field, it is affected very distinctly, and even strongly, by the near approximation of soft iron or magnets, and after the following manner. Let fig. 1 represent in plan the position of the two chief magnetic poles, and of a piece of crystallized bismuth between them, which, by its magnecrystallic condition, points axially. Then, if a piece of soft iron be applied against the cheek of the pole, as at *e*, and also near to the bismuth, as at *a*, it will affect the latter and

Fig. 1.

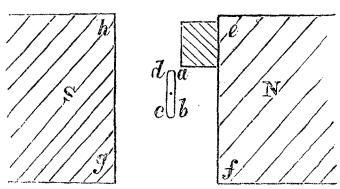


cause its approach to the iron. If the iron be applied in a similar manner at *f*, *g*, or *h*, it will have a like result in causing motion of the bismuth; and the parts marked *b*, *c* and *d*, will in turn approach it, seeming to be attracted. If the soft iron do not touch the magnetic pole, but be held between it and the bismuth so as to represent generally the same positions, the same effects, but in a weaker degree, are produced.

2488. Though these motions seem to indicate an effect of attraction, I do not believe them to be due to any such cause, but simply to the influence of the law of action (2479.) before expressed. The previously uniform condition of the magnetic field is destroyed by the presence of the iron; lines of magnetic force, of greater intensity than the others, proceed from the angle *a* of the iron in the position represented, or from the corresponding angles in the other positions (the shape of the pole now approximating more or less to the conical or pointed form), and therefore the crystal of bismuth moves round on the axis of suspension, that it may place the line of magnecrystallic force parallel or as a tangent to the resultant of the magnetic forces which pass through its mass.

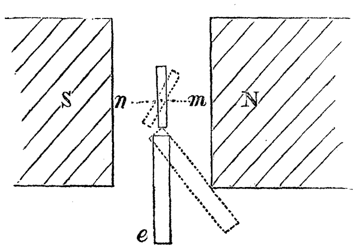
2489. When in place of the group of crystals a crystalline plate of bismuth (2481.) is employed, the appearances produced under similar circumstances, are those of *repulsion*; for if fig. 2 be allowed to represent this state of things, the piece of iron applied at *e* causes the plate to recede from it at *a*, or if applied at *f*, *g*, or *h*, it causes recession of the bismuth from it at the points *b*, *c*, and *d*. Now though these effects look like repulsion, they are, as I conclude, nothing more than the consequences of the endeavour which the bismuth makes, under the law before expressed (2479.), to place the magnecrystallic line of force parallel to, or as a tangent to the resultant of magnetic force passing through the bismuth.

Fig. 2.



2490. A piece of iron wire about $1\frac{1}{2}$ inch long, and 0·1 or 0·2 of an inch thick, being held in the equatorial plane to the edge of the plate (fig. 3), did not alter its position; but if the end *e* were inclined to either pole, the plate began to move, and moved most when the iron touched the pole as in the figure. When it approached or touched the N pole, the inclination of the crystal plate of bismuth was as indicated by the dotted figure. When it touched the S, the inclination was the contrary way. If the end *e* were kept in contact with the N pole, and the other end of the soft iron rod placed in the position *m*, the bismuth was not affected; but if then this subsidiary pole were moved the one way or the other towards the edge of the plate, the latter turned as the pole moved, always tending to keep its face towards it, and evidently by the tendency of the magnecrystallic axis to place itself parallel to the resultant of magnetic force

Fig. 3.



passing through the bismuth. The same results were obtained with the crystal (2487.) under similar circumstances, and corresponding results were obtained when the soft iron rod was applied between the S cheek of the magnet and the bismuth. The like effects were also obtained with plates of arsenic and antimony.

2491. When a magnet is used instead of soft iron, corresponding effects are produced; only, it must be remembered, that if the chief magnet be very powerful, it may often neutralize, and even change, the magnetism of the small approximated magnet; and this can happen with the latter (as to external influence) whilst in the magnetic field, even though when withdrawn it may appear to remain unaltered.

2492. Thus, when the plate of bismuth was suspended between the cheeks of the horse-shoe magnet (2485.), fig. 2, and the north pole of a small magnet (the blade of a pocket-knife) was placed at *a* or *b*, it caused recession of the part of the bismuth near it, and precisely for the same reasons as those that existed when the soft iron was there. When the extra pole was placed at *c* or *d*, the action was more feeble than in the former case, and consisted in an approximation of that part of the bismuth to the pole. As this position of the subordinate pole would terminate and neutralize certain of the lines of magnetic force proceeding from the south pole of the horse-shoe magnet, so the resultant of the lines of force passing through the bismuth would be changed in direction, being rendered oblique to their former course, and precisely in the manner represented by the motion of the bismuth, in its tendency to place its line of force parallel with them in their new position.

2493. An approximated south pole caused motions in the contrary direction.

2494. When the subordinate pole was applied to the edge of the plate, the little magnet being in the equatorial position (fig. 3), then instead of being neutral, as the iron was, it caused the plate to move in a tangential direction, either to the right or the left, according as it was either a south or a north pole, just indeed as the iron did when, by inclining it, the approximated end became a pole (2490.). This effect was shown in a still more striking degree by using the crystal of bismuth (2487.), because, from its form and position the magnetic curves most affected by the extra pole were more included in the bismuth than when the plate was used.

2495. Innumerable variations of these motions may be caused, and appearances of attraction or repulsion, or tangential action be obtained at pleasure by the use of crystals having the magnecrystallic axis corresponding with their length, or plates where it accords with their thickness; and either permanent or temporary subsidiary magnetic poles. By making the moveable pole travel slowly round the bismuth from the neutral point *m* to the other neutral point *n*, fig. 3, a summary of the whole can be obtained, and it is found that they all resolve themselves into the general law before expressed (2479.): the magnecrystallic axis and the resultant of magnetic force passing through the bismuth, tending to become parallel.

2496. Hence a small crystal or plate of bismuth (or arsenic (2532.)) may become

a very useful and important indicator of the direction of the lines of force in a magnetic field, for at the same time that it takes up a position showing their course, it does not by its own action tend sensibly to disturb them.

2497. Many of these motions are similar to, and have relation with, those described by PLÜCKER, REICH, and others, as obtained by the action of iron and magnets on bismuth, in its simple diamagnetic condition. These results are by them and others considered as indicating that the bismuth, as I had originally supposed (2429, &c.), has really in its diamagnetic state, a magnetic condition the reverse of that of iron. I am not acquainted with all of them, or with the reasoning thereon (being in the German language); but such as I am aware of, and have reobtained, seem to me to be simple results of the law I formerly laid down (2267. 2418.), namely, that diamagnetic bodies tend to proceed from stronger to weaker places of magnetic force: and give no additional or other proof of the assumed reverse polarity of bismuth than the former cases of action which I had given, coming under that law.

2498. Supposing that the intervening or surrounding matter might, in some manner, affect the magnecrystallic action of bismuth and other bodies, I fixed the magnetic poles at a given distance (about two inches) asunder, suspended a crystal of bismuth in the middle of the magnetic field, and observed its vibrations and set. Then, without any other change, I introduced screens of bismuth, being blocks about two inches square and 0·75 of an inch in thickness, between the poles and the crystal, but I could not perceive that any change in the phenomena was produced by their presence.

2499. The bismuth crystal (2459.) was suspended in water between the magnetic poles of the horse-shoe magnet. It set well in accordance with the general law (2479.), and it took five revolutions of the torsion index at the upper end of the suspending silk filament to displace it, and cause it to turn into the diametral position. This is, as well as I could observe the results, the same amount of torsion force required to effect its displacement when the crystal was placed in the same position, but surrounded with air only.

2500. The same bismuth was then suspended in a saturated solution of protosulphate of iron (adapted as a magnetic medium), it set as before with apparently no change of any kind; and when the torsion force was put on, it still required five turns of the index, as before, to cause the displacement of the crystal, and its passage into the diametral position.

2501. Whether therefore crystals of bismuth be immersed in air, or water, or solution of sulphate of iron, or placed between thick masses of bismuth, if they be subject to the same magnetic force, the magnecrystallic force exerted by them is the same both in nature, direction and amount.

2502. It seemed possible and probable that magnetic force might affect the crystallization of bismuth, if not of other bodies. For, as the force affects the mass of a crystal by that power which its particles possess, and which they give to the crystal as a whole by their polar (or axial (2472.)) and symmetric condition; and, as the final position of the crystalline mass in the magnetic field may be considered as that of the least constraint, so it was likely enough that, if the bismuth in a fluid state were placed under the influence of the magnetism, the individual particles would tend to assume one and the same axial condition, and the crystalline arrangement and direction of the mass upon its solidification, be in some degree determined and under government.

2503. Some bismuth, therefore, was fuzed in a glass tube and held in a fixed position in the strong magnetic field until it had become solid; then, being removed from the glass, it was suspended so that it might assume the same position under the influence of the magnet; but no signs of *magnecrystallic* force were evident. It was not expected that the whole would become regularly crystallized, but that a *difference* between one direction and another might appear. Nothing of the kind however occurred, whatever the direction in which the piece was suspended; and when it was broken open, the crystallization within was found to be small, confused, and in all directions. Perhaps if longer time were allowed, and a permanent magnet used, a better result might be obtained. I had built many hopes upon the process, in reference to the crystalline condition of gold, silver, platina, and the metals generally, and also in respect of other bodies.

2504. I cannot find that crystals of bismuth acquire any power, either temporary or permanent, which they can *bring away* from the magnetic field. I held crystals in different positions in the field of intense action of a powerful electro-magnet, having conical terminations very near to each other; and, after some time, removed them and applied them instantly to a very delicate astatic magnetic needle; but I could not perceive that they had the least extra effect upon it, because of such treatment.

2505. As a crystal of bismuth is subject to, and obeys the influence of, the lines of magnetic force (2479.), so it follows that it ought to obey even the earth's action, and point, though with a very feeble degree of power. I have suspended a good crystal by a single long filament of cocoon silk, and sheltered it as well as I could from currents of air by concentric glass tubes, and I think have observed indications of a set or pointing. The crystal was so hung that the magnecrystallic axis made the same angle with the horizontal plane (about 70°) as the magnetic dip, and the indication was, that the axis and the dip tended to coincide: but the experiments require careful repetition.

2506. A more important point, as to the nature of the polar or axial forces of bis-

muth, is to know whether two crystals, or uniformly crystallized masses of bismuth, can mutually affect each other; and if so, what the nature of these affections are? what is the relation of the equatorial and terminal parts? and what, the direction of the forces? I have made many experiments, in relation to this subject, both in and out of the magnetic field, but obtained only negative results. I employed however small masses of bismuth, and it is my purpose to repeat and extend them at a more convenient season with larger masses, built up, if necessary, in the manner already described (2483.).

2507. I need hardly say that a crystal of bismuth ought to point in a helix or ring of wire carrying an electric current, and so that its magnecrystrallic axis should be parallel to the axis of the ring or helix. This I find experimentally to be the case.

¶ ii. *Crystalline Polarity of Antimony.*

2508. *Antimony* is a *magnecrystallic* body. Some crystalline masses, procured in the manner before described (2457.), were broken up with copper tools, and some excellent groups of crystals were obtained, weighing from ten to twenty grains each, in which all the constituent crystals appeared to be uniformly placed. The individual crystals were very good on the whole, and much more frequently full at the faces and complete than those of bismuth. They were very bright, having a steel-gray or silvery appearance, and to the eye appeared more surely as cubes than bismuth, though here and there distinctly rhomboidal faces presented themselves. Planes of cleavage can be made to replace the solid angles; and, as with bismuth, there is one plane generally brighter and more perfect than the others.

2509. In the first place, it was ascertained that all these crystals were diamagnetic, and strongly so.

2510. In the next it was ascertained, as with bismuth, that all of them exhibited the magnecrystallic phenomena with considerable power, showing the existence of a line of force (2470.), which, when placed vertically, left the crystal free to move in any direction (2476.); but when placed horizontally, caused the crystal to point, and in so doing took up its own position parallel to the resultant of magnetic force passing through the crystal (2479.). This line proceeded, as in bismuth, from one of the solid angles to the opposite one, and was perpendicular to the bright cleavage plane just spoken of (2508.).

2511. So, generally, the action of the magnet upon these crystals was the same as upon the crystals of bismuth; but there are some points of variation which require to be more distinctly stated and distinguished.

2512. In the first place, when the magnecrystallic axis was horizontal, and a certain crystal used, upon the evolution of the magnetic force, the crystal went up to its position slowly, and pointed as with a dead set. If the crystal were moved from this position on either side, it returned to it at once: there was no vibration. Other crystals did the same imperfectly; and others again made one or perhaps two vibra-

tions, but all appeared as if they were moving in a thick fluid, and were, in that respect, utterly unlike bismuth, in the freedom and mobility with which it vibrated (2459.).

2513. In the next place, when the crystals were so suspended as to have the magnecrystallic axis vertical, there was no pointing nor any other signs of magnecrystallic force; but other appearances presented themselves. For, if the crystalline mass was revolving when the magnetic force was excited, it suddenly stopped, and was caught in a position which might, as was found by experience, be any position; but if the greatest length was out of the axial or equatorial position, the arrest was followed by a *revulsive* motion on the discontinuance of the electric current (2315.). This revulsive motion was never great, but was most when the length of the mass formed about an angle of 45° with the axis of the magnetic field.

2514. On further examination it appeared that this arresting and revulsive effect was precisely the same in kind as that observed on a former occasion with copper and other metals (2309.), and due to the same cause, namely, the production of circular electric currents in the metal under the inductive force of the magnet. Now, the reason appeared why, in the former case, the crystals of antimony did not oscillate (2512.); and why, also, they went up to their position of rest with a dead set; for the currents produced by the motion are just those which tend to stop the motion (2329.)*; and though the magnecrystallic force was sufficient to make the crystal move and point, yet the very motion so produced generated the current which reacted upon the tendency to motion, and so caused the mass to advance towards its position of rest as if it moved in a thick fluid.

2515. Having this additional knowledge respecting the arrest and revulsion of the antimony (effects dependent upon its superior conducting power, in this compact crystalline state, as compared with bismuth), one has no difficulty in identifying the magnecrystallic force of this metal with that of the former, and the correspondence of the results in all essential characters and particulars. In most of the pieces of crystals of antimony the force seemed less than in bismuth, but the fact may not really be so, for the inductive current action just described, tends to hide the magnecrystallic phenomena.

2516. Different pieces of antimony also seem to differ from each other in their setting force, and also in their tendency to exhibit revulsive effects; but these differences are either only apparent, or may easily be explained. The arresting and revulsive action depends much upon the continuity of the mass, so that one large piece shows it much better than several small pieces, and these again better than a

* Any one who wishes to form a sufficient idea of the arresting powers of these induced currents, should take a lump of solid copper, approaching to the cubical or globular form, weighing from a quarter to half a pound; should suspend it by a long thread, give it a rapid rotation, and then introduce it, spinning, into the magnetic field of the electro-magnet; he will find its motion to be instantly stopped; and if he further tries to spin it, whilst in the field, will find it impossible to do so.

powdered substance. Even the revulsive action of copper may be entirely destroyed by reducing the single lump to filings. It is easy to perceive, therefore, that of two groups of antimony crystals, each symmetrically disposed within itself, the one may have larger crystals well connected together, as regards the induction of currents through the whole mass, and the other smaller crystals less favourably united. These would present very different appearances, as regards the arrest of motion and succeeding revulsive action; and further, on that very account, would differ in their readiness to present the magnecrystallic phenomena, though they might possess precisely equal degrees of that force.

2517. On proceeding to experiment with plates of antimony, further illustrations of the effects resulting from the causes just described were obtained, with abundant accompanying evidence of the existence of the magnecrystallic condition in the metal. The plates were selected from broken masses, as with bismuth (2480.). Some were soon found which acted simply, instantly, and well; their large surfaces were bright cleavage planes. When suspended by any part of the edge, these planes faced towards the magnetic poles; and the plate oscillated on each side of its final position, gradually acquiring its state of rest.

2518. When these plates were suspended with their planes horizontal, they had no power of pointing in the magnetic field. When they were inclined, the points which were most depressed below and raised above the horizontal plane, were those which took up their places nearest the magnetic poles (2482.).

2519. When several plates were arranged together into a consistent bundle (2483.), the *diamagnetic* effect was removed, and the magnecrystallic oscillation and pointing became very ready and characteristic.

2520. Thus it is evident that, in all these cases, there was a line of magnecrystallic force perpendicular to the planes of the plates, and perfectly consistent in its position and action with the force before found in the solid crystals of antimony.

2521. But another plate of antimony was now selected, which had every appearance of being able to present all the phenomena of the former plates; and yet, when hung up by its edge, it showed no signs of magnecrystallic results; for it first advanced a little (2310.), then was arrested and kept in its place, and if standing between the axial and equatorial positions, was revulsed when the battery current was interrupted, exhibiting effects equal to those of copper (2315.). Many other plates were tried with precisely the same result.

2522. When this plate (2521.) was placed in the field of intense power between two *conical* magnetic poles, it exhibited the same phenomena; but notwithstanding the arresting action, it moved slowly until it stood in the equatorial position; a result which was probably due to the exertion of both *magnecrystallic* and *diamagnetic* force. When the plate was suspended with its planes horizontal, the arresting and revulsive actions were gone; for the induced currents which before caused them could not now exist in the necessary vertical plane; further, it had no setting power,

which showed that there was no axis of magnecrystallic force in the length or breadth of the plates.

2523. Other plates were then found able to produce mixed effects, and those in different degrees. Thus, some, like the first, vibrated freely, pointed well, and presented no indication of the arrest and revulsive phenomena. Others vibrated sluggishly, set well, and showed a tendency to be arrested. Others pointed well, going up to their place with a dead set, but moving as if in a fluid ; or, if the magnetic force were taken off before the piece had settled, it was revulsed feebly : and others were caught at once, did not set (within the time of my observation), and were strongly revulsed.

2524. Finally, a careful investigation, carried on by means both of the horse-shoe (2485.) and the great electro-magnet (2247.), made the cause of these differences in the effects apparent.

2525. It may be observed, in the first place, that sometimes a plate of antimony being selected (2517.), having planes very bright and perfect in their appearance, and, therefore, giving reason to think that it may point well in the magnetic field, when submitted to the horse-shoe magnet does not do so; but points obliquely, feebly, and perhaps in two undiametral positions. This is, I have no doubt, because the crystallization is complicated and confused. Such a plate, if it be sufficiently broad and long (i. e. not less than a quarter or one-third of an inch), when submitted to the electro-magnet, will show the arresting (2310.) and revulsive (2315.) action well.

2526. In the next place, we have to remember that, for the development of the induced currents that cause the arresting and revulsive action, the plate must have certain sufficient dimensions in a vertical plane (2329.). The currents occur in the mass and not round the separate particles (2329.), and the resultant of the magnetic lines of force passing through the substance, is the axis round which these currents are produced. Hence the reason why the effect does not occur with plates suspended in the horizontal position, which yet produce it well in the vertical position ; a result which a disc half an inch in diameter of thin foil or plate, being copper, silver, gold, tin, or almost any malleable metal will show ; though the best conductors are the fittest for the purpose. Now this condition is of no consequence in respect of *magnecrystallic* action, and a narrow plate has as much force as a broad one, having the same mass. The first plate that I happened to select (2517.) was well crystallized, thick and narrow ; hence it was favourable for magnecrystallic action, unfavourable to the arresting and revulsive action, and showed no signs, comparatively, of the latter.

2527. When a broad and well-crystallized plate is obtained, then both sets of effects appear : thus, if the plate is revolving when the magnetic force is brought into action, it quickens its velocity for an instant, then is stopped ; and if the magnetic force is at once taken off, it is revulsed, exactly as a piece of copper would be

(2315.). But if the magnetic force be continued, it will then be perceived that the stop is only apparent; for the plate moves, though with a greatly reduced velocity, and continues to move until it has taken up its magnecrystallic position. It moves as if in a thick fluid. Hence the magnecrystallic force is there and produces its full effect; and the reason why the appearances have changed is, that the very motion which the force tends to give, and does give to the mass, causes those magneto-electric currents (2329.) which by their mutual action with the magnet tends to stop the motion; and therefore its slowness and the final dead set (2512. 2523.).

2528. A magnet which is weaker (as the horse-shoe instrument described (2485.)) produces the currents by induction in a much weaker degree, and yet manifests the magnecrystallic power well; hence it is more favourable, under certain circumstances, for such investigations; as it helps to distinguish the one effect from the other.

2529. It will readily be seen that plates, whether of the same metal or of different metals, cannot, even roughly, be compared with each other as to magnecrystallic force by their vibrations; for under the influence of these induced currents, plates of the same magnecrystallic force oscillate in very different manners. I took a plate, and by cement (2458.) attached selected paper to its faces, and then observed how it acted in the magnetic field; it set slowly, and it showed the arresting and revulsive effects (2521.). I then pressed it in a mortar, so as to break it up into many parts, which still kept their place; and now it set more freely and quickly, and showed very little of the revulsing action.

2530. Though the indication by vibration is thus uncertain, the torsion force still remains to us, I believe, a very accurate indication of the strength of the set (2500.); and, therefore, of the degree of the magnecrystallic force; and though the suspending silk fibre may give way a little, a glass thread, according to RITCHIE's suggestion, would answer perfectly.

2531. Antimony must be a good conductor of electricity in the direction of the plates of the crystals, or it would not give, so freely, these indications of revulsive action. The groups of crystals of antimony (2508.) showed the effect in such a degree, as to make me think that the constituent cubes possessed the power nearly equally in all directions. A piece of finely crystallized or granular antimony does not, however, show it in the same proportion; from which it would seem as if an effect equivalent in some degree to that of division occurs, either at the meeting of two incongruous crystals, or between the contiguous plates of the crystals, and affects the conducting power in these directions.

¶ iii. *Crystalline Polarity of Arsenic.*

2532. A mass of the metal arsenic exhibiting crystalline structure (2480.), was broken up, and several plates selected from the fragments, having good cleavage plane surfaces, about 0·3 of an inch in length, 0·1 inch in width, and 0·03 in thick-

ness. These, when suspended opposite one conical pole, proved to be perfectly diamagnetic; and when before it or between two poles strongly *magnecrystallic*. I have a pair of flat-faced poles with screw-holes in the centre of the faces, and these so much weaken the intensity of the lines of magnetic force about the middle of the field, when the faces are within half an inch of each other, that a cylinder of granular bismuth 0·3 in length sets *axially*, or from pole to pole (2384.). But with the plates of arsenic between the same poles there was no tendency of this kind; so much was the magnecrystallic force predominant over the diamagnetic force of the substance.

2533. When the plates of arsenic were suspended with their planes horizontal, then they did not point at all between the flat-faced poles. Any inclination of the planes to the horizontal line produced pointing, with more or less force as the planes approached more or less to the vertical position, exactly in the manner already described in relation to bismuth and antimony (2482. 2518.).

2534. Thus, arsenic with bismuth and antimony are found to possess the magnecrystallic force or condition.

Royal Institution,
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